Salinity and sodium hazards of three streams of different agricultural land use systems in Ile-Ife, Nigeria

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Abstract In this study, three streams—Amuta, Agbogbo and Abagbooro were examined for salinity and sodium hazards and suitability of the water for irrigational purpose. The three streams are located within areas of three different agricultural practices and land uses. Water samples from the streams were collected twice a month for 1 year. Irrigation water quality parameters assessed included pH, electrical conductivity (EC), sodium adsorption ratio (SAR), percentage sodium, permeability index and potential salinity. Water samples were analyzed using standard chemical procedures. Results of the irrigation water quality parameters studied showed that water samples from the three streams do not exhibit toxicity problem in relation to salinity and sodium hazard. Although the data obtained for the three catchment areas for pH, EC and SAR were closely related, least concentrations of these irrigation water indices were obtained for Abagbooro stream where there is secondary forest; highest concentrations were found in Agbogbo stream and moderate values were obtained for water from Amuta stream where subsistent and mechanized farming are practiced, respectively.

Keywords Stream · Salinity · Sodium adsorption ratio · Infiltration · Permeability and toxicity

Introduction

One of the many demands for water apart from urban, industrial and recreational uses is agriculture. For most countries, agriculture is the major user of water resources for irrigated farming and the livestock sector, while its impact on water quality is also significant in many cases (OECD 2006). Thus, agriculture has become a critical cause and a source of water pollution that might upset the nutrition cycle in the watercourses and soil–water systems and render the water unsuitable or less valuable for other water uses (Bo Appलगren 2004). The need for improving the management of water resources by agriculture is now widely recognized in view of the global pressure on water resources associated with growing populations and food demand (OECD 2006).

Availability of water by itself is not a guaranty for sustainable development, but its fitness for specific purposes like irrigation, industrial and domestic uses. However, poor quality of both surface and groundwater is not only a limiting factor in crop production but its indiscriminate and constant use cause salinity and alkalinity (Muhammad et al. 2002). Apparently, most water contains dissolved salts and trace elements, many of which result from the natural weathering of the earth's surface. Agricultural runoffs or surface-water-logging could result in environmental menace as a result of anthropogenic activities. These runoffs may alter the chemical quality of both stream and ground waters which in turn render them unsuitable for some purposes in agriculture especially irrigation (Sudhakar and Mamatha 2004).

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Irrigated agriculture consumes 60–80 % of the total water usages, and contributes nearly in 38 % of the global food production (Shahinasi and Kashuta 2008). It has played a major role in generating employment opportunities in the rural areas and providing food for cheap prices for low income families and middle class ones in the urban area (Shahinasi and Kashuta 2008).

Irrigation water is applied to supplement natural precipitation or to protect crops against freezing or wilting. Inefficient irrigation can cause water quality problems (USEPA 2005). Thus, there is a need to evaluate irrigation water quality and this is hinged majorly on alkalinity (sodium hazard) and salinity hazard (total soluble salt content) of such water (Silva 2004). The main problem of irrigation water with high sodium concentration is its effect on soil permeability and water infiltration. An infiltration problem occurs if the irrigation water does not enter the soil rapidly enough during a normal irrigation cycle to replenish the soil with water needed by the crop before the next irrigation. Sodium also contributes directly to the total salinity of the water and may be toxic to sensitive crops such as fruit trees. However, the most influential water quality guideline on crop productivity in the water salinity hazard is measured by electrical conductivity (EC). The primary effect of high EC water on crop productivity is the inability of the plant to compete with ions in the soil solution for water thereby leading to physiological drought. The higher the EC, the less water is available to plants, even though the soil may appear wet, i.e., usable plant water in the soil solution decreases dramatically as EC increases (Bauder et al. 2007). Ayers and Westcot (1985) as well as Oster (2001) reported that infiltration rates are particularly sensitive to sodium adsorption ratio (SAR) and salinity. The two most common water quality factors which influence the normal infiltration rate are the salinity of the water and its sodium content relative to the calcium and magnesium content. High salinity water, therefore, will increase infiltration. Low salinity water or water with high sodium to calcium and magnesium ratio will decrease infiltration. Both factors may operate at the same time. The infiltration rate generally increases with increasing salinity and decreases with either decreasing salinity or increasing sodium content relative to calcium and magnesium—SAR. Therefore, the two factors, salinity and SAR provide information on its ultimate effect on water infiltration rate (Nata et al. 2009).

One of the earliest published schemes in the USA was that of Schofield (1936) who gave a good review of the factors affecting the suitability of waters for irrigation. He deduced water quality criteria based on field observation of their effects and reported these for a given soil, a given climate and a given group of crops. He considered waters as doubtful for irrigation with EC values >2 dS/m and

sodium percentage >60 %. Although this scheme was regional, but later theoretical studies carried out indicated the use of SAR as a more theoretically sound basis for sodium hazard assessment (NWQMS 2000).

Thus, irrigation water quality is a key environmental issue faced by the agricultural sector (Shahinasi and Kashuta 2008) and it is against the backdrop that this study was set up to examine the suitability of three streams of different agricultural practices for irrigational purposes in the context of their alkalinity (sodium content) and salinity. Earlier study on the streams focused on the determination of physicochemical parameters and trace metals of water from these streams under different agricultural land use. This study revealed the levels of impairment caused by different agricultural activities and practices on the quality of stream waters. Variation in the levels of the parameters reported was a reflection of different agricultural practices utilized in the study area (Ogunfowokan et al. 2009).

Study area

The study area (Fig. 1) covered three streams located in Amuta, Agbogbo and Abagbooro farmlands in Ile-Ife. These streams are tributaries of River Shasha, one of the regional rivers in Southwestern Nigeria, and are located between $7^{\circ}30'N$ $4^{\circ}30'E$ and $7^{\circ}34'N$ $4^{\circ}34'E$. The basin areas (km^2) of Amuta, Agbogbo and Abagbooro streams are 0.35, 0.44 and 0.15 km^2 , respectively. The annual rainfall averaged 1,413 in a 3-year survey (2005–2007) and showed two peaks: one in July and the other in September. The mean temperature ranges from 22.5 to 31.4°C . Amuta farmland's geology consists of mica schist, while Agbogbo and Abagbooro farmlands mostly consist of granitic gneiss. Soils in Amuta River are ferruginous tropical soils, generally described as Tropudalf and Paleustult (Amusan et al. 2005). The soils in Agbogbo generally belong to the Typic Rhodustults group (Ogunkoya 2000), while Abagbooro is covered by soils of the Iwo series (Smyth and Montgomery 1962).

Land use system in Amuta is characterized by mechanized farming in which agricultural practice involves the use of tractors for weeding and planting in addition to the use of fertilizers, herbicides, pesticides and other agrochemicals to augment crop production. In Abagbooro farmland, tree crops like cocoa, kola-nut, palm tree, and orange are cultivated. Thus, closed canopy together with a forest floor covered by a thin layer of leaf litter which is underlain by highly permeable topsoil may reduce soil erosion. The agricultural practice of Agbogbo, however, is that of peasant farming system. Unlike Abagbooro farmland, most crops in this catchment are arable and include cassava, maize, cocoyam, vegetable and pepper. Therefore, there is no vegetation cover and the soil is much more

Fig. 1 Map of the study area in Ile-Ife showing the three rivers and sampling stations

prone to soil erosion and leaching. In addition, weeding is done traditionally, using cutlass and hoe with little or no use of fertilizers, herbicides and pesticides.

Methodology

Water samples were collected twice in a month for 1 year (July 2005–June 2006) from the three catchment areas into pretreated polyethylene sampling bottles using standard method of sampling technique (APHA 1999). Nitric acid digestion method (APHA 1999) was used to digest the water samples. Concentrations of metals (Na^+ , K^+ , Ca^{2+} and Mg^{2+}) in the digested samples were determined at the Centre for Energy Research and Development at the Obafemi Awolowo University, Ile-Ife, Nigeria, using Alpha-4 Atomic Absorption Spectrophotometer.

Bicarbonate alkalinity (HCO_3^-) concentration in the water samples was determined by titrimetric method (Ademoroti 1996).

Salinity

Salinity (total soluble salt content) of the stream samples was evaluated in terms of EC (dS m^{-1}) (DERM 2009; Page et al. 1982; Rashidi and Seilsepour 2008a) using Wtw Lf 90 electrical conductivity meter at the sampling sites.

Alkalinity

Alkalinity was expressed in terms of:

1. SAR (DERM 2009, Rashidi and Seilsepour 2008b; Karanth 1987)

$$\text{SAR} = \frac{[\text{Na}^+]}{\sqrt{\frac{1}{2}([\text{Ca}^{2+}] + [\text{Mg}^{2+}])}}$$

2. Sodium percentage (Na%) (Al-Salim 2009; Siamak and Srikantaswamy 2009)

$$\text{Na}\% = \frac{(\text{Na}^+ + \text{K}^+)}{(\text{Ca}^{2+} + \text{Mg}^{2+} + \text{Na}^+ + \text{K}^+)} \times 100$$

Permeability index

Permeability index (PI) for the water samples was determined using the formula developed by Doneen (1964) and Siamak and Srikantaswamy (2009):

$$\text{PI} = \frac{\text{Na}^+ + \sqrt{(\text{HCO}_3^-)}}{(\text{Ca}^{2+} + \text{Mg}^{2+} + \text{Na}^+)} \times 100$$

Potential salinity

Potential salinity (PS) was defined as the chloride concentration plus half of the sulfate concentration.

$$\text{PS} = \text{Cl}^- + \text{SO}_4^{2-}/2$$

All the analyses in this study were done in triplicate and the data obtained were subjected to descriptive analysis.

Results and discussion

The pH of the three studied streams ranged from 6.99 to 8.60 (mean value of 7.59), 6.10 to 7.70 (mean value of 7.10), and 6.67 to 7.75 (mean value of 7.22) for Amuta, Agbogbo and Abagbooro stream, respectively (Table 1). These values were within the permissible limit for irrigated agriculture water pH of 6.5–9.2 (DOE 1997) and the normal pH ranking for irrigation water of 6.0–8.5 (Table 2) (Shahinasi and Kashuta 2008). Hence, the three streams were considered to pose no restriction to irrigation use. A continued long-term use of waters outside this pH range could eventually alter naturally occurring pH levels in surface soils to which they are applied and therefore could possibly lead to micro-nutrient imbalances and potential future crop production and fertility problems (Alberta Environment 2000).

All waters used for irrigation purposes contain some amount of dissolved salt (salinity) which generally comes from weathering of soil, leaching of salts dissolved from geologic marine sediments into the soil solution or groundwater, and flushing of salts off roads, landscapes and stream banks during and after precipitation events. Typically, irrigation water salinity in arid and semi-arid areas is greater than that of humid and sub-humid areas (Bauder et al. 2007). Electrical conductivity is a useful and reliable index for the measurement of water salinity or total dissolved solids in water. Electrical conductivity in water is due to ionization of dissolved inorganic solids—minerals, salts, metals, cations or anions that dissolved in water. Thus, salinity of any form of water used for irrigation is determined by its electrical conductivity value. The electrical conductivity or salinity values obtained in this study were: 0.08, 0.06 and 0.05 (dS/m) for Amuta, Agbogbo and Abagbooro streams, respectively. It is evident from the data in Table 1 that all the electrical conductivity values for water samples from the three streams were suitable for irrigation purposes, because their values were within 0 and 3 dS/m (Table 2) stipulated range for normal electrical conductivity ranking for waters meant for irrigation purposes (Shahinasi and Kashuta 2008). Saline conditions restrict or inhibit the ability of plants to take up water and

Table 1 Irrigation water parameters of the study area in meq/l

Month	Stream	pH	EC (dS/m)	HCO ₃ ⁻	Cl ⁻	SO ₄ ⁻²	Na ⁺	K ⁺	Ca ²⁺	Mg ²⁺	SAR	Na%	PI (%)	PS
July	Amuta	6.99	0.08	0.906	0.123	0.093	0.728	0.188	0.014	0.018	5.76	96.62	221.05	0.170
	Agbogbo	6.55	0.05	0.493	0.087	0.074	0.994	0.389	0.010	0.014	9.07	98.29	166.60	0.124
	Abagbooro	6.67	0.05	0.468	0.087	0.048	0.386	0.180	0.010	0.004	4.61	97.59	267.70	0.111
August	Amuta	8.10	0.08	0.854	0.145	0.062	0.520	0.244	0.006	0.018	4.75	96.95	265.44	0.176
	Agbogbo	7.00	0.05	0.561	0.145	0.078	0.676	0.177	0.003	0.013	7.56	98.16	205.92	0.184
	Abagbooro	7.10	0.05	0.533	0.116	0.084	0.527	0.124	N.D.	0.003	3.61	99.54	237.17	0.158
September	Amuta	7.80	0.07	0.771	0.109	0.126	0.627	0.179	N.D.	0.021	6.12	97.46	232.25	0.172
	Agbogbo	7.60	0.04	0.471	0.145	0.127	0.738	0.120	0.003	0.002	4.76	99.42	191.66	0.209
	Abagbooro	7.75	0.04	0.511	0.073	0.080	0.494	0.160	0.013	0.006	5.07	97.18	235.67	0.113
October	Amuta	7.50	0.09	0.814	0.044	0.067	0.641	0.164	N.D.	0.012	8.28	98.53	236.29	0.078
	Agbogbo	7.40	0.06	0.432	0.022	0.067	1.617	0.145	0.047	0.025	8.52	96.07	134.64	0.056
	Abagbooro	7.30	0.04	0.431	0.022	0.029	0.477	0.166	0.001	0.007	7.54	98.77	233.81	0.037
November	Amuta	7.15	0.09	0.746	0.073	0.068	0.631	0.098	0.011	0.015	5.53	96.56	227.55	0.107
	Agbogbo	7.00	0.06	0.476	0.094	0.106	0.688	0.104	0.011	0.004	7.94	98.14	196.02	0.147
	Abagbooro	7.25	0.05	0.449	0.094	0.046	0.464	0.128	0.008	0.008	5.19	97.37	236.25	0.117
December	Amuta	7.80	0.09	1.129	0.073	0.055	0.654	0.111	0.006	0.010	7.31	97.95	256.27	0.101
	Agbogbo	7.70	0.07	0.729	0.218	0.064	0.730	0.079	0.003	0.010	9.05	98.42	213.19	0.250
	Abagbooro	7.70	0.05	0.728	0.218	0.045	0.535	0.114	N.D.	0.008	8.46	98.78	255.62	0.241
January	Amuta	7.40	0.09	1.128	0.290	0.065	0.550	0.065	0.070	0.246	1.38	66.06	186.14	0.323
	Agbogbo	7.10	0.07	0.811	0.363	0.089	0.430	0.048	0.054	0.042	1.96	83.28	253.04	0.408
	Abagbooro	7.70	0.06	0.651	0.218	0.041	0.258	0.094	0.067	0.055	1.04	74.26	280.26	0.239
February	Amuta	8.60	0.10	1.205	0.435	0.072	0.593	0.059	0.085	0.319	1.32	61.74	169.61	0.471
	Agbogbo	7.40	0.07	0.814	0.435	0.101	0.413	0.057	0.096	0.075	1.41	73.32	225.17	0.486
	Abagbooro	7.10	0.05	0.726	0.290	0.065	0.258	0.073	0.007	0.027	1.98	90.68	380.14	0.323
March	Amuta	7.20	0.08	0.722	0.145	0.090	0.488	0.072	N.D.	0.010	6.90	98.25	268.67	0.190
	Agbogbo	7.10	0.07	0.730	0.470	0.095	0.425	0.112	0.049	0.054	1.87	83.91	242.23	0.518
	Abagbooro	6.90	0.06	0.721	0.363	0.072	0.241	0.089	0.006	0.022	2.04	92.18	405.20	0.399
April	Amuta	7.50	0.08	0.775	0.218	0.098	0.602	0.107	0.006	0.013	6.18	97.39	238.65	0.267
	Agbogbo	6.10	0.07	0.651	0.507	0.099	0.439	0.045	0.007	0.038	2.93	91.49	257.44	0.557
	Abagbooro	6.90	0.06	0.732	0.363	0.111	0.327	0.084	0.010	0.023	2.55	92.57	328.61	0.419
May	Amuta	7.60	0.07	0.644	0.102	0.083	0.545	0.103	0.007	0.018	4.87	96.28	236.32	0.144
	Agbogbo	7.00	0.06	0.735	0.450	0.087	0.521	0.095	0.016	0.022	3.78	94.19	246.51	0.494
	Abagbooro	7.10	0.05	0.570	0.116	0.047	0.301	0.111	0.011	0.020	2.42	93.00	318.07	0.140
June	Amuta	7.40	0.09	0.565	0.290	0.086	0.617	0.110	0.015	0.020	4.66	95.41	209.97	0.333
	Agbogbo	7.30	0.07	0.812	0.496	0.105	0.688	0.137	0.011	0.028	4.93	95.49	218.57	0.549
	Abagbooro	7.20	0.06	0.640	0.218	0.065	0.275	0.080	0.011	0.035	1.81	88.53	334.89	0.251
Overall mean	Amuta	7.59	0.08	0.855	0.171	0.080	0.600	0.125	0.018	0.060	5.26	91.60	229.02	0.211
	Agbogbo	7.10	0.06	0.643	0.286	0.091	0.697	0.126	0.026	0.027	6.15	92.52	212.58	0.332
	Abagbooro	7.22	0.05	0.597	0.182	0.061	0.379	0.117	0.014	0.018	4.69	93.37	292.78	0.212

pH has no unit

nutrients, regardless of whether the salinity is caused by irrigation water or soil water which has become saline because of additions of salty water, poor drainage, or a shallow water table. Plants absorb water through a process of ‘osmo-regulation’, where at elevated salt concentration within plants, the movement of water from the soil surrounding root tissue into the plant root is induced.

When the soil solution salinity is greater than the internal salinity of the plant, water uptake is restricted. This condition retards the growth of any affected plant which in turn might reduce plants yield. Considering the irrigation water salinity ratings based on electrical conductivity in Table 3, however, the EC values reported in this study generally are <0.65 dS/m, therefore the water salinity ranking is very

Table 2 Guidelines for interpretation of irrigation water quality

Water parameter	Symbols	Units	Normal ranking in irrigation water	Range in Amuta ^a	Range in Agbogbo ^a	Range in Abagbooro ^a
Electrical conductivity	EC _w	dS/m	0–3	0.07–0.10	0.04–0.07	0.04–0.06
Calcium	Ca ²⁺	meq/l	0–20	N.D.–0.006	0.003–0.096	N.D.–0.067
Magnesium	Mg ²⁺	meq/l	0–5	0.010–0.319	0.002–0.075	0.003–0.055
Sodium	Na ⁺	meq/l	0–40	0.488–0.728	0.413–0.994	0.241–0.527
Bicarbonate	HCO ₃ [−]	meq/l	0–10	0.565–1.129	0.432–0.814	0.431–0.732
Chloride	Cl [−]	meq/l	0–30	0.073–0.435	0.022–0.507	0.022–0.363
Sulfate	SO ₄ ^{2−}	meq/l	0–20	0.055–0.126	0.064–0.127	0.029–0.111
Potassium	K ⁺	meq/l	0–0.052	0.059–0.244	0.045–0.389	0.073–0.180
Acid/basic	pH	1–14	6.0–8.5	6.99–8.60	6.10–7.70	6.67–7.70
Sodium absorption ratio	SAR	meq/l	0–9	1.32–8.28	1.41–9.07	1.04–8.46

Adapted from Shahinasi and Kashuta (2008)

^a This study

low and hence will be suitable for sensitive crops. Based on the general guidelines for assessment of salinity hazard of irrigation water (Table 4), results obtained in the waters from the three streams were below the 0.75 dS/m guidelines and showed that none of the water samples is likely to exhibit salinity hazard for irrigation. In a situation where water salinity is extremely high, plant tissue may die off, thereby exhibiting necrosis at the leaf edges. However, saline water may lead to concentrations of some elements which can be toxic to plants. Some examples of frequently occurring specific-ion toxicities include boron, sodium, and chloride (Bauder et al. 2007).

Doneen (1964) described potential salinity of irrigation water by pointing out that the suitability of water for

Table 4 General guidelines for assessment of salinity hazard of irrigation water and electrical conductivity range of samples from the study area

	Limitation		
	None	Moderate	Severe
EC _w (mmhos/cm or dS/m) ^a	<0.75	0.75–3.0	>3.0
Range in Amuta	0.07–0.10	–	–
Range in Agbogbo	0.04–0.07	–	–
Range in Abagbooro	0.04–0.06	–	–

^a Adapted from Miller and Gardiner (2001) and Western Fertilizer Handbook (1995)**Table 3** Irrigation water salinity ratings based on electrical conductivity

EC (dS/m)	Water salinity rating	Plant suitability	Range in Amuta ^a	Range in Agbogbo ^a	Range in Abagbooro ^a
<0.65	Very low	Sensitive crops	0.07–0.10	0.04–0.07	0.04–0.06
0.65–1.3	Low	Moderately sensitive crops	–	–	–
1.3–2.9	Medium	Moderately tolerant crops	–	–	–
2.9–5.2	High	Tolerant crops	–	–	–
5.2–8.1	Very high	Very tolerant crops	–	–	–
>8.1	Extreme	Generally too saline	–	–	–

Adapted from DNR (1997)

^a This study

irrigation is not only dependent on the concentration of soluble salts. It has been reported that the low solubility salts precipitate and accumulate in the soil for successive irrigation whereas the concentration of highly soluble salts increases the salinity of the soil (Siamak and Srikantaswamy 2009). The average potential salinity of the study area was 0.211, 0.332 and 0.212 meq/l (Table 1) for Amuta, Agbogbo and Abagbooro streams, respectively.

In this study, carbonate was found mainly in the form of bicarbonate in all the water samples, because carbonate alkalinity (phenolphthalein alkalinity) was zero in all samples. Bicarbonate (HCO₃[−]) content of the surface water samples ranged from 0.565 to 1.129 meq/l in Amuta stream, 0.432 to 0.814 meq/l in Agbogbo stream and 0.431 to 0.732 meq/l in Abagbooro stream (Table 1). These results may not cause any irrigational problem as they were within the range of recommended guidelines for irrigation water quality of 0–10 meq/l (Ayers and Westcot 1985; Shahinasi and Kashuta 2008) (Table 2). Higher values of bicarbonate cause problem like corrosion in water pipelines (Siamak and Srikantaswamy 2009).

It has been reported that chloride is not adsorbed or held back by soils, but it moves readily with the soil–water into

the crop. It travels in the transpiration stream and accumulates in the leaves. Thus, excessive chloride could cause necrosis (dead tissue) in plants which is often accompanied by early leaf drop or defoliation (Ayers and Westcot 1994). The ranges of chloride content in water samples from Amuta (0.044–0.435 meq/l), Agbogbo (0.022–0.507 meq/l) and Abagbooro (0.022–0.363 meq/l) (Table 1) were within the tolerance limit for irrigation water. The recommended limit is 4.23–6.90 meq/l (DOE 1997; Nahid et al. 2009) and normal ranking limit of chloride in irrigation water is 0–30 meq/l (Table 2). Hence, chloride concentrations obtained in this study may not be injurious to plants. Relationship between concentration of chloride in irrigation water and its effect on crops is given in Table 5. Present study shows that the results of chloride concentrations from waters of the three streams are generally safe for all plants. Sulfate contents of the surface water samples ranged from 0.055 to 0.126 meq/l in Amuta, 0.064 to 0.127 meq/l in Agbogbo and 0.029 to 0.111 meq/l in Abagbooro (Tables 1). Although the sulfate concentrations in the study area vary considerably, all the values fall within acceptable limits of 8.40 meq/l (DOE 1997; WHO 1983) and the normal ranking limit of (0–20 meq/l) for water meant for irrigation purpose (Table 2). High concentration of this anion in irrigation water can readily stimulate the growth of algae and aquatic weeds.

Sodium is one of the important metals that serve as essential nutrients necessary for some biochemical functions. It is often found in natural waters due to its high solubility and frequently associated with salinity problems when linked to chloride and sulfate ions. The sodium concentrations obtained in this study ranged from 0.488 to 0.728 meq/l in Amuta, 0.413 to 0.994 meq/l in Agbogbo and 0.241 to 0.535 meq/l in Abagbooro (Table 1).

Table 5 Chloride classification of irrigation water

Chloride (meq/l)	Effect on crops	Range in Amuta ^a	Range in Agbogbo ^a	Range in Abagbooro ^a
Below 2.03	Generally safe for all plants	0.073–0.435	0.022–0.507	0.022–0.363
2.03–4.06	Sensitive plants show injury	–	–	–
4.07–10.15	Moderately tolerant plants show injury	–	–	–
Above 10.15	Can cause severe problems	–	–	–

Adapted from Mass (1990)

^a This study

It is evident that all concentrations of sodium found in the water from the three streams were far below the recommended limits of 8.70 meq/l for irrigation use (DOE 1997; WHO 1983; Nahid et al. 2009). In minute quantities, sodium is beneficial to the growth of some plants, while at higher concentrations it is toxic to many plants. High levels of sodium can cause three effects on plant growth: (1) excess sodium accumulates in leaves, causing leaf burn and possibly defoliation; (2) development of poor soil physical conditions which limit plant growth; and (3) calcium and magnesium deficiency through reduced availability and imbalance with respect to sodium (NWQMS 2000).

Potassium is another major nutrient for plants and it could be derived from inorganic fertilizer. It is also a component of total salts found in any form of water system as all potassium salts are soluble in water. Potassium (K^+) cation behaves similarly to that of sodium in the soil and is commonly found in natural waters in only small amounts. Recommended guideline for potassium concentration in irrigation water according to DOE (1997) is 0.308 meq/l. The concentration of potassium in water samples from the study area varied considerably as follows: 0.059–0.244 meq/l in Amuta, 0.045–0.289 meq/l in Agbogbo and 0.073–0.180 meq/l in Abagbooro (Table 1). These results may not pose any irrigational problem because they were below the regulatory concentration and the normal ranking range of potassium (0–0.052) in irrigation water (Table 2).

Calcium is one of the most abundant natural elements in the environment and generally found in all natural waters. It has higher concentration in water from limestone area when compared to that from non-calcareous area. Calcium in the form of gypsum is commonly applied to improve physical properties of tight soils because it makes soil friable and also allow water to drain readily through soil. Thus, irrigation water that contains ample calcium concentration is most desirable. Although concentrations of calcium in all the three sites used as the study area were low, they were within the permissible limit for irrigation water as set by DOE (1997) and WHO (1983) which are 3.75 and 10 meq/l, respectively. Calcium concentration in Amuta and Abagbooro streams ranged from non-detected to 0.070 and 0.067 meq/l. However, in Agbogbo stream, it was between 0.003 and 0.096 meq/l (Table 1).

Magnesium content of water is considered as one of the most important qualitative criteria in determining the quality of water for irrigation. Generally, calcium and magnesium maintain a state of equilibrium in most waters. More magnesium in water will adversely affect crop yields as the soils become more alkaline (Dhirendra et al. 2009). Magnesium and calcium could be used to establish and explain relationship between sodium hazard and total salinity in irrigation water. All water samples for this study can be used without restriction for irrigation based on the

results obtained for magnesium because they are much lower than the recommended limits of 2.5–2.95 meq/l (DOE 1997) and 4.17 meq/l (WHO 1983). Magnesium content was 0.010–0.319 meq/l in Amuta, 0.002–0.075 meq/l in Agbogbo and 0.003–0.055 meq/l in Abagbooro (Table 1).

Sodium or alkali hazard in the use of water for irrigation is determined by the absolute and relative concentration of cations, i.e., the proportion of sodium (Na^+) to calcium (Ca^{++}) and magnesium (Mg^{++}) ions in a water sample and it is expressed as SAR. SAR is an important parameter for the determination of suitability of water for irrigation purpose because it is responsible for the sodium hazard in irrigation water (Siamak and Srikantaswamy 2009). Low values of SAR were obtained for the water samples of the three sampling sites: Amuta (1.32–8.28), Agbogbo (1.41–9.07) and Abagbooro (1.04–8.46) (Table 1). These results show that waters from the study area are excellent and fall within category 1 in Table 6, and are suitable for irrigation on almost all soil types with little danger of the development of harmful levels of exchangeable sodium. The levels of SAR reported in this study are within the normal ranking (0–9) expected in irrigation water (Table 2). The degree to which irrigation water tends to enter into cation-exchange reactions in soil can be indicated by the SAR (Dhirendra et al. 2009). Excess sodium in waters produces undesirable effects of changing soil properties and reducing soil permeability (Dhirendra et al. 2009). Sodium, when replacing adsorbed calcium and magnesium becomes hazardous as it causes damage to the soil structure. It makes soil to be compact and impervious. Hence, the assessment of SAR in water is necessary while considering its suitability for irrigation.

There is a significant relationship between SAR values of irrigation water and the extent to which sodium is absorbed by the soil. High concentrations of sodium in soils affect its physical condition and soil structure, resulting in the formation of crusts, water-logging, reduced

soil aeration, reduced infiltration rate and reduced soil permeability; excessive concentrations of sodium in soils may also be toxic to certain types of crops. SAR gives a very reliable assessment of water quality of irrigation waters with respect to sodium hazard, since it is more closely related to exchangeable sodium percentages in the soil than the simpler sodium percentage (Tiwari and Manzoor 1988).

An infiltration problem related to water quality occurs when the normal infiltration rate for the applied water or rainfall is appreciably reduced and water remains on the soil surface too long or infiltrates too slowly to supply the crop with sufficient water to maintain acceptable yields. SAR and salinity combination could be used to assess irrigation water quality in relation to infiltration or permeability problem (Nata et al. 2009).

Most of SAR value obtained in this study fell in the range 6–12 while EC was below 0.5 dS/m; therefore, from Table 7, water infiltration problem may occur in the future in those three study areas irrespective of their different agricultural practices. In this regard, the %Na values and the corresponding EC of the waters of the three rivers were plotted within the Wilcox (1955) diagram (Fig. 2) to confirm the irrigation classes of the waters. Indeed, the waters plotted within the Excellent to Good class, but the plots were in the top corner range that abutted the Permissible to Doubtful class on account of the high %Na. Water infiltration problems could occur if sodium were retained in the cation-exchange complex.

As an extension, Doneen's (1964) model for assessing the suitability of water for irrigation based on the PI was also used to classify the waters. Accordingly, waters can be classified as Class I, Class II and Class III orders. Class I and Class II waters are categorized as good for irrigation with 75 % PI or more. Class III water is unsuitable with 25 % of maximum permeability (Dhirendra et al. 2009). Permeability index of water samples of the three catchment areas used for this study was more than 100 % (Table 1);

Table 6 General classification of irrigation water based upon SAR values

SAR	Category	Precaution and management suggestions	Range in Amuta ^a	Range in Agbogbo ^a	Range in Abagbooro ^a
0–10	1 (low Na water)	Little danger	1.32–8.28	1.41–9.07	1.04–8.46
10–18	2 (medium Na water)	Problems on fine texture soils and sodium sensitive plants, especially under low-leaching conditions. Soils should have good permeability	–	–	–
18–24	3 (high Na water)	Problems on most soils. Good salt tolerant plants are required along with special management such as the use of gypsum	–	–	–
24	4 (very high Na water)	Unsatisfactory except with high salinity (>2.0 dS/m), high calcium levels and the use of gypsum	–	–	–

Adapted from Siamak and Srikantaswamy (2009)

^a This study

Table 7 Combined effect of electrical conductivity (EC_w) of irrigation water and sodium adsorption ratio (SAR) on the likelihood of water infiltration (permeability) problems

Sodium adsorption ratio (SAR) of irrigation water	Water infiltration problem	
	Unlikely when EC_w (dS/m) is more than	Likely when EC_w (dS/m) is less than
0–3	0.6	0.3
3–6	1.0	0.4
6–12	2.0	0.5
12–20	3.0	1.0
20–40	5.0	2.0

Source: Ayers and Westcot (1985)

Fig. 2 A plot of sodium percentage and electrical conductivity for classification of the waters of the three rivers (based on Wilcox 1955). Blue dots dry season mean values of the rivers. Black dots annual mean values of the rivers (1, Amuta; 2, Agbogbo; 3, Abagbooro)

consequently, waters from the studied streams are of good irrigation quality. But as earlier noted, given the high %Na of the waters, permeability could be impaired in the future if sodium were retained in the exchange complex.

Conclusion

In this study, salinity and sodium hazards of three streams under different agricultural land use systems have been carried out. All the irrigation water quality parameters examined in the study do not exhibit toxicity problem in relation to salinity and sodium hazard. Although data on parameters analyzed for water samples from the three catchment areas were closely related, least concentrations

were obtained from Abagbooro stream while those of Agbogbo were the highest. Moderate values of irrigation water indices obtained for Amuta stream may be attributed to modern farming system that is practiced on the farmland. Generally, all the water samples analyzed from the three streams are suitable for irrigational purposes and will hence bring about good performance and yield for agricultural sector. However, there is the need for routine checks to ascertain the suitability or otherwise of these water sources from time to time so as to forestall permeability and infiltration problems among irrigational water quality challenges that could retard food production in the studied community.

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